Effects of fire disturbance on the forest structure and succession in the natural broad-leaved/Korean pine forest

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Abstract: Investigations on charcoal in the soil, fire-scarred trees, stand composition, forest structure as well as regeneration status were carried out in the natural broad-leaved/Korean pine *(Pinus koraiensis)* forest after fire disturbance at Liangshui Nature Reserve on the mid-north of Xiaoxing'an Mountains from 1990 to 1992, and the ecological effects of fire disturbance on the formation and succession of this kind of forest were analyzed according to the survey results. The average depth of charcoal in the soil was related to the timing of the fire. According to the characteristic of fire-scarred trees, the dynamic map of the fire behavior was drawn onto the topographic map. It showed that the dimension and extent of the fire disturbance was closely related with site conditions. Fire disturbance only led to a significant difference in stand composition and diameter class structure for the stands at different locations, rather than completely destroying the forest. After fire disturbance, the horizontal community structure was a mosaic of different patches, which were made up of different deciduous species or different sizes of Korean pines, and the succession trend of each patch was also different. In the sites with the heavy fire disturbance, the intolerant hardwood species were dominant, and there were a large number of regenerative Korean pine saplings under the canopy. In the moderate -disturbed sites, the tolerant hardwood species were dominant, and a small number of large size Korean pines still survived. In the light-disturbed sites, large size Korean pines were dominant.

Key words: *Pinus koraiensis*; Natural forest; Fire disturbance; Succession
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Introduction

The natural broad-leaved/Korean pine (*Pinus koraiensis*) forest were once the most widespread forest type in the mountainous area of northeastern China. However most of them have disappeared due to several decades of intensive cutting and other human-related disturbances. Therefore this forest ecosystem has become endangered and attracted increasing concerns (Liu 1957; Ge 1993; Shao 1995; Ian 2003). Extensive studies have been carried out on the structure, function and dynamics of this forest ecosystem (Li 1964; Ge 1990; Ge & Li 1995; Dale *et al.* 1998; Andrew 2001). These studies showed that the horizontal pattern of the natural broadleaf/Korean pine forest consisted of even-aged patches at different generations, which was caused by the natural regeneration of Korean pine-gap-phase regeneration. It has been recognized that gap-phase regeneration plays a key role in sustaining the natural broad-leaved/Korean pine forest (Watt 1947; Ge 1992; Shao 1995; Kari *et al.* 1996; Kevin 1997). The scale of gaps was decided by the effect intensity of disturbance factors. Small canopy gaps were proved to be formed by small disturbances, such as wind, and mortality of individual old trees. Large gaps were speculated to be caused by fire and logging (Ge 1993; Yoh 1995; Peter 1998; Zang 1999; Ole 2000; Hong 2002).

The main objective of this study is to investigate the mark of fire disturbance (the charcoal layer in the soil and remnant scars on stems) in the natural broad-leaved/Korean pine forest at Liangshui Nature Reserve, and then study its effects on forest horizontal structure and succession trend. This will provide an important basis for further studying the sustaining mechanism of the natural broad-leaved/Korean pine forest.

Methods and materials

Study site

This study was conducted on the natural broad-leaved/Korean pine forest at Liangshui Nature Reserve (47°10' N, 128°53' E), on the mid-north of Xiaoxing'an Mountains, northeastern China. The nature reserve preserves one of the largest remnant natural broad-leaved/Korean pine forests. The topography of the study site is characterized with low mountains and hills. Elevation ranges from 300 m to 700 m. The climate is continental monsoon, with a cold and dry winter and warm and rainy summer. Annual mean temperature is -0.3 ℃, annual minimum temperature is -6.6 ℃ in January, and annual maximum temperature is 7.5 ℃ in July. Annual precipitation is 600-700 mm and about 60 percent concentrates in June, July and August. The zonal soil type is the Dark Brown Forest Soil.

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Zonal vegetation is the broadleaf-conifer mixed forest, which is dominated by Korean pine, accompany with many warm broadleaved species such as *Betula platyphylla, Populus davidiana, Tilia amurensis,* and *Acer mono*, and cold-temperature speciessuch as *Picea asperata* and *Abies fabric.*

Study design

Fieldwork was carried out at the natural broad-leaved/Korean pine forest from 1990 to 1992, which once went through fire disturbance. The distribution of charcoal, fire-scar trees and forest composition were investigated separately.

(1) *Investigation of the distribution of charcoal.* Ten plots were randomly set up at different compartments. Quadrat size was 20 cm X 20 cm. Soil pit was dug at each sampling location and soil charcoal was stratified sampling to measure the size and distribution depth of charcoal. At the meantime, the structure characteristic and regeneration of Korean pine forest were investigated, including forest composition, species, diameters at breast height and the number of sapling and seedling of Korean pine.

(2) *Investigations of fire-scarred trees and forest composition.* Fire disturbance to Korean pines was identified by fire scars at the bottom of stems. The occurring time of fire was estimated by crossing-sections of fire-scarred trees. The direction, shape and width of scars were investigated to identify the direction and intensity of fire. A 50-hm^2 plot was selected for measuring the direction and size of scars on each remained tree. Twenty sample plots (the area of each sample is 0.1 hm^2) were set up to measure the diameter and height of the tree with diameter bigger than 1.0 cm. The regeneration status of the natural broad-leaved/Korean pine forest was assessed according to the evenness of horizontal distribution and the number of seedlings and saplings of less than 1.0 cm in diameter.

Results

Distribution of charcoal

Charcoal was investigated in each plot. Quantity of charcoal, closely related with the stand type, was large in the soil of Korean pine forest mixed with *Quercus mongolica* or *Tilia amurese*, lesser in Korean pine forest mixed with *Betula costata*, and least in Korean pine forest mixed with *Picea asperata* or *Abies fabric.* This result was congruent with the analysis of combustibility of the natural broad-leaved/Korean pine forest in Xiaoxing'an Mountains (Zheng 1982).

According to the determinate fire chronology of Korea pine reserve, the mean depth of charcoal in the soil was closely correlative with the history of fire disturbance (Table 1). Forest, which underwent fire disturbance 206 years ago, had been restored completely and later dominated by Korean pine. In this forest, the distribution of charcoal was deep, whereas the distribution of charcoal in the forest undergone fire disturbance later was shallow. In latter forest, traces of fire disturbance still existed in the forest structure and composition, such as a large number of broadleaf species (*Betula platyphylla* and *Populus davidiana*) distributed in clusters.

Table 1. The distribution of charcoal after fire disturbance in different years

Time of fire disturbance	Depth /cm	Number of plots	Slope	Forest characteristics	Regeneration of *Pinus koraiensis*
40 years ago	Under the ground layer	1	10-20°	Stand was dominated by *Populus davidiana* and *Betula platyphylla.*	Regeneration and growth in good status.
110 years ago	2-4	5	5-35°	Distribution of *Pinus koraiensis* was uneven, accompanied with *Tilia amurensis, Acer mono, Pbellodendron amurense, Fraxinus mandshurica* and *Betula costat. Populus davidiana* and *Betula platyphylla* were dominant in local	The number of seedlings and saplings was great. Growth status was in good order. Individuals still existed in the succession layer.
260 years ago	10-20	4	5-30°	*Populus davidiana* was dominant, accompanied with shade-tolerant species, such as *Tilia amurensis, Betula platyphylla* and *Fraxinus mandshurica.*	Regeneration of *Pinus koraiensis* was in bad status. The number of saplings was few.

Regular pattern of fire burning

The regular pattern of fire burning could be speculated by the distribution locations of fire scars and surviving trees. According to the investigation for more than 200 surviving individuals of Korean pine, with fire disturbance 110 years ago, the shapes of fire scars, which was related to intensity of fire, were divided into two types: triangle scar and linear scar (Fig.1). For light fire-injured tree, its fire scar presented a narrow gap (linear scar) in the stem with tree growing and the mortality of heartwood was low, while for the heavy fire-injured individual, the fire scar presented a triangle shape, such trees are likely to suffer from plant diseases and pests and mortality of heartwood was very high. In the

investigated forest, the surviving trees with triangle scar accounted for 70%.

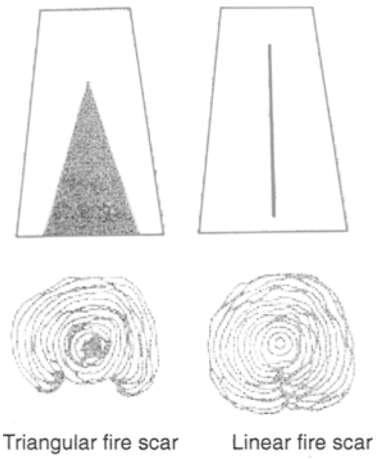

Fig. 1 The shapes of fire scars on surviving Korean pines after fire disturbance

Height of linear fire scars and hemline width of triangular fire scars were measured respectively. The height of linear fire scar was in range of 0.2-1.0 cm, and the width of triangle fire scar was in range of 10-40 cm (Fig.2, Fig.3). Based on the results, we could speculate that the intensity of fire disturbance was not severe, and the occurred fire belonged to surface fire.

According to the investigations of fire scars and the stump, the diameters of stump of survived Korean pines mostly ranged from 20 cm to 40 cm after fire disturbance occurred. This indicated the degree of fire resistance of Korean pine tree had a relation with its diameter class. Individuals of this diameter class had strong resistance to fire, thus most of them survived and became existing fire-scarred trees.

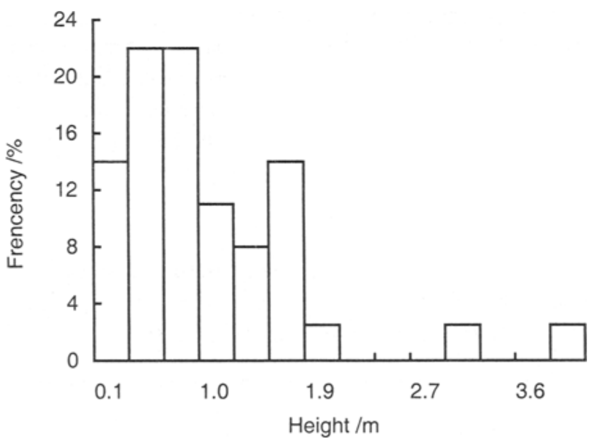

Fig. 2 The distribution of height frequency of linear fire scar of surviving Korean pines after fire disturbance

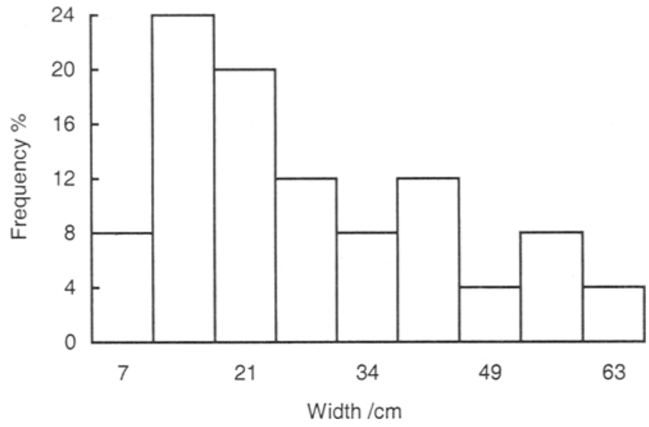

Fig. 3 The distribution of hemline width frequency of triangle fire scars of surviving Korean pines after fire disturbance

Fire dynamics influenced the distribution direction of fire scars on the stem. Except for a part quantity of heat was taken away by free wind, the rest came round stems and fire scars formed in the leeward of stems. In this study we investigated the direction and distribution of fire scars on all the survived Korean pines in the sample plot (50 hm^2) to protract the dynamics map of fire disturbance on the topographic map (Fig.4). It showed that the direction of fire scars in survived trees was consistent with the sharp slope, and they distributed in the side of the upgrade. When fire spread from the downgrade to the upgrade, or on the gentle slope, the direction of fire scars was not consistent and closely related with local microtopography, and the fire scars mainly distributed in the well-drained side.

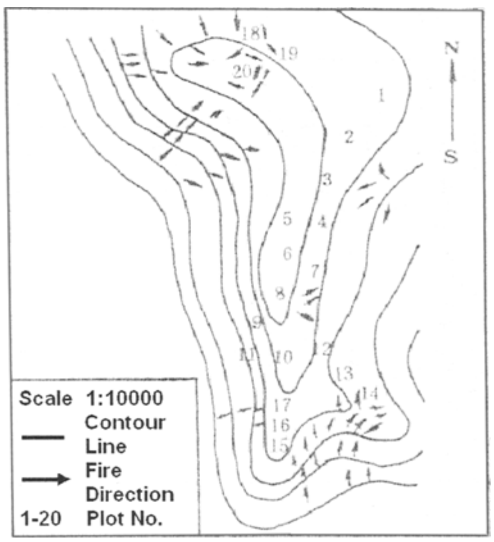

Fig. 4 Fire disturbance dynamic and topographic form

Effects of fire disturbance on forest structure and succession process

According to the evenness of horizontal distribution and number of seedlings and saplings in twenty plots, we as-

sessed the regeneration status of the natural broad-leaved/Korean pine forest. The distribution of Korean pines was not even and the proportion of associated broadleaf species was bigger, especially *Populus davidiana* and *Betula platyphylla* in patches (Table 2).

By Table 2 and Fig.4, combined with the aerial photography, we could protract the horizontal structure map of forest after fire disturbance (Fig.5). From Fig 5 it can be seen that through the succession of 110 years, the stands at different site conditions had different responses to fire disturbance. This difference led to the clear diversity of the forest composition, structure and succession trend in different sites of the same forest.

Table 2. Forest structure characteristics of the natural broadleaved/Korean pine forest after fire disturbance

Plot No.		Average diameter						Area /hm^2	Species composition	Regeneration of Korean pines
		P.K.	B.P.	A.M.	T.A.	B.C.	P.A. /A.F.			
I	1	29.7	--	10.6	14.0	19.2	16.8	0.10	5P.K.+3T.A.+2P.A./A.F.	In bad order
	2	39.7	--	10.2	15.6	16.1	25.6	0.10	7P.K.+2P.A./A.F.+1T.A.	
	9	38.2	39.5	16.7	25.0	12.1	3.9	0.10	7P.K.+2T.A.+1P.A./A.F.	
	12	25.2	26.3	12.1	23.1	--	14.1	0.10	6P.K.+1P.A.+2T.A.+1B.P.	
	13	60.7	14.3	--	14.8	10.5	18.5	0.10	7P.K.+2P.A.+1T.A.	
	14	58.1	--	17.1	20.1	--	14.3	0.10	5P.K.+3P.A.+2T.A.	
	19	38.5	--	13.5	29.6	31.9	11.8	0.10	6P.K.+3T.A.+1A.M.	
	18	40.3	--	11.6	24.1	9.1	25.4	0.10	6P.K.+3A.F.+1T.A.	
II	20	--	30.5	14.3	26.7	31.7	9.2	0.10	7A.M.+2T.A.+1P.A.	In moderate order
	4	20.8	28.5	6.7	23.3	4.0	18.4	0.10	5T.A.+3P.K.+2U.P.	
	5	15.7	3.5	12.2	20.1	9.6	8.3	0.10	4T.A.+3P.K.+2B.P.+1Pb.A.	
	6	10.2	26.3	9.5	17.8	--	7.0	0.10	4T.A.+4P.K.+1Pb.A.+1A.M.	
	7	5.6	33.7	10.8	24.7	3.1	--	0.10	4T.A.+4P.K.+1B.P.+1A.M.	
III	3	13.7	31.0	12.6	21.1	--	25.4	0.10	5B.P.+2T.A.+2P.A.+1P.K.	In good order
	8	2.7	30.1	11.8	16.0	27.1	7.0	0.10	6B.P.+2T.A.+2A.M.	
	10	26.0	25.0	10.9	13.9	--	6.5	0.10	7B.P.+2P.K.+1A.M.	
	15	6.6	19.5	9.1	13.8	--	11.8	0.10	7B.P.+1T.A.+1P.A.+1A.M.	
	11	6.8	19.5	7.6	15.3	18.0	7.0	0.10	5B.P.+3T.A.+2P.K.	
IV	11	14.0	14.7	8.4	17.9	--	9.8	0.04	5P.D.+2P.K.+2P.A.+1B.P.	In good order
	17	5.9	15.4	8.9	12.5	--	8.0	0.04	4P.D.+3B.P.+2P.A.+1P.K.	

Note: *P.K.: Pinus koraiensis, P.A.: Picea asperata, A.F.: Abies fabric, B.P.: Betula platyphylla, T.A.: Tilia amurensis, A.M.: Acer mono, U.P.: Ulmus pumila, P.D.: Populus davidiana, Pb.A.: Pbellodendron amurense, F.M.: Fraxinus mandshurica, B.C.: Betula costata.*

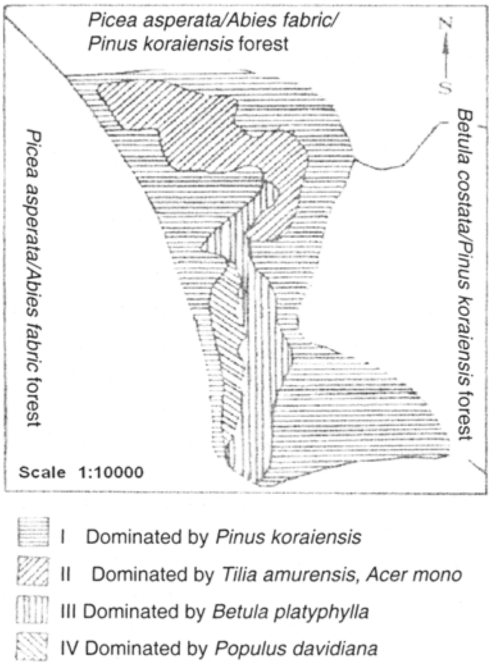

Fig. 5 Forest horizontal structure after fire disturbance

Fire disturbance made the forest composition and structure take on mosaics in space, and increased forest diversity. On the edge of the forest, as here the terrain was generally gentle fire disturbance was light and many trees with a big size class remained, so the forest in this area still kept the structure characteristic of natural mature forest. In the midst of the ridge, fire disturbance was heavy, and less trees with a big size class remained. Here top canopy was dominated by the shade tolerance species—*Tilia amurensis*, *Acer Mono* and *Ulmus pumila*, and the quantities of *Populus davidiana* and *Betula platyphylla* were little. Sparse forest canopy was due to fire disturbance. In the gap, the surviving saplings, which regenerated before fire occurrence, grew into the mid size class and then entered into the succession layer (10-15 m), while the regenerated seedlings after the fire had become individuals of the small size class (4-6 m) and occupied the regeneration layer. In sharp slope and the upper of slope, where the intensity of fire disturbance was heavy, the intrinsic forest structure was destroyed on the whole by fire and almost no individuals remained. Here heliophilous broadleaf species (*Populus davidiana* and *Betula platyphylla*) were dominant and

therewere plenty of regenerated seedlings and small size class individuals.

Forest had different succession trends in space and formed a special succession series after fire disturbance. After 110 years, the diameter structure took on reverse "J" shape (Fig.6a). Fire disturbance had changed the dynamic character of natural broad-leaved/Korean pine forest—only seedlings but no saplings exist in the mature Korean pine forest. The diameter structure was investigated in the regions of I, II, III and IV (Figs. 6b, 6c, 6d). The result showed that the population dynamics of Korean pine was significantly different in different locations. Old-generation Korean pine took on an ascendant trend in region I, and forest was in the climax stage. Broadleaf species with great shade tolerance occupied the overstory in region II, and mid-generation Korean pine was subrogated by broadleaf species in the local. In region III and IV, young-generation Korean pine grew in bloom in the regeneration layer and broadleaf species (*Populus davidiana* and *Betula platyphylla*) in the top began to decay. These Korean pine groups in different regions and different development stages comprised of the steady population structure of the natural broad-leaved/Korean pine forest.

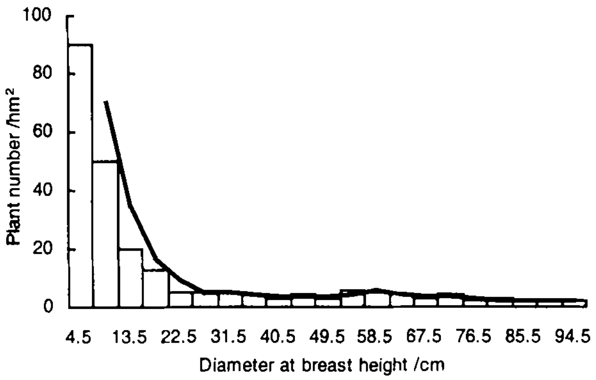

Fig. 6a The size class structure of Korean pine population in the whole region

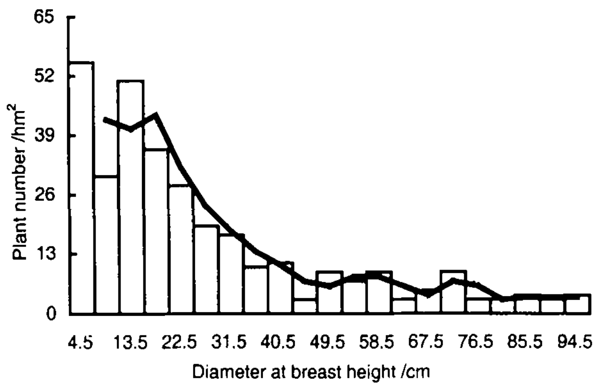

Fig. 6b The size class structure of Korean pine population in the region I

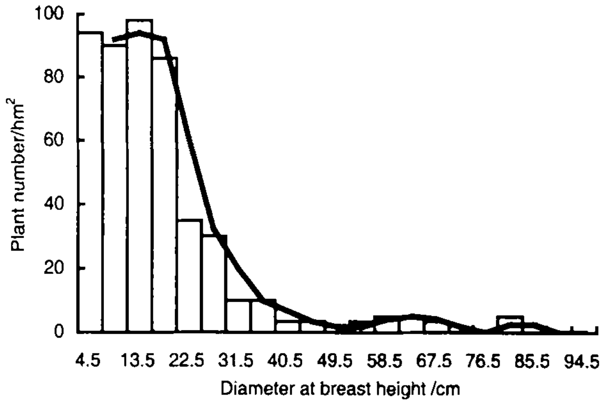

Fig. 6c The size class structure of Korean pine population in the region II

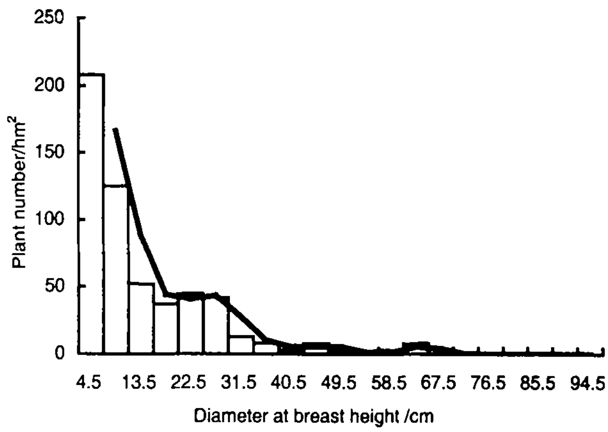

Fig. 6d The size class structure of Korean pine population in the region III, IV

Discussion and conclusions

Forest fires are widespread phenomena in most of forest as a way of the natural selection. In forest zone, the distribution and existence of pines have a close relationship with fire disturbance. Our study showed that all the mature Korean pine forests in Liangshui Natural Reserve lived through fire disturbance in different extents during their development stage. However fire disturbance, in the most cases, did not exceed the elasticity limit of ecosystem in respect of the whole forest ecosystem of natural broad-leaved/Korean pine forest. As a result of different stand conditions the intensity of fire disturbance in different locations was inconsistent. When fire occurred in the natural forest, different size gaps were formed. These gaps increased the diversity of forest structure and were beneficial to the regeneration and growth of Korean pines. With the growth of forest, its composition and structure became into the mosaics, and different succession trends presented in the horizontal, and at last developed into a steady-going

succession series.

Based on this study, we can conclude that the average depth of charcoal in the soil was related to the timing of the fire., The dynamic map of the fire behavior, which was drawn onto the topographic map according to the characteristic of fire-scarred trees, showed that the dimension and extent of the fire disturbance was closely related with stand conditions. Fire disturbance only led to a significant difference in stand composition and diameter class structure for the stands at different locations, rather than completely destroying the forest. The horizontal community structure was a mosaic of different patches, which were made up of different deciduous species or different sizes of Korean pines, and the succession trend of each patch was also different. In the site with the heavy fire disturbance, the intolerant hardwood species were dominant, and there were a large number of regenerative Korean pine saplings under the canopy. In the moderate -disturbed sites, the tolerant hardwood species were dominant, and a few large size Korean pines still survived. In the light-disturbed sites, large size Korean pines were dominant.

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